The Advantages of a Magnetron Source for Electron Spin Echo Detection

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Abstract: A pedestal pulsed magnetron can give a sequence of phase coherent microwave pulses at high power. It has been demonstrated that this method can be used for electron spin echo generation. The advantages of this method over the more conventional technique is discussed.

In most studies of electron spin echoes at frequencies up to 35 Ghz, the conventional method of generation the high power microwave pulses needed is to use a low power continuous wave oscillator followed by fast microwave switches, driven by the pulse programmer, and then the resultant microwave pulses (of order 10 to 100 ns width) are amplified by a pulsed travelling wave amplifier (TWTA) which is switched off after the last pulse, to avoid its noise interfering with the detection of very low level microwave signals produced by the spin echoes. The early studies of Mims did not use this approach, rather the pulses were generated by rapid switching of the travelling wave tube by voltages applied to the grid of the tube. Although not recommended by the manufacturers, Mims was able to use this over a long period without destroying the tube, presumably as an ex-nuclear physicist he knew how to generate high voltage flat topped pulses, i.e. without overshoot and ringing on the rising edge. The manufacturers were surprised that his tube did not fail after a short period![1]. I was told by a defence consultant[2] that it was discovered that phased array radar could not be done with TWTAs switched by the method used in ESE studies, as there were phase shifts from pulse to pulse. It now seems that workers in the field recognise that phase shifts can occur pulse to pulse in ESE studies and have managed to overcome the problem[3].

The use of a pedestal pulsed magnetron for pulse sequences was disclosed in a patent assigned to the University of Essex [4] . The basic process is to apply a pedestal voltage to the magnetron i.e. a long pulse of a voltage lower than the Hartree voltage, above which the magnetron oscillates. Phase coherence pulse to pulse is achieved by application to the magnetron of a low level signal, of order 100mW, from a continuous wave source, in our case from a 100 Mhz crystal oscillator derived generator. The magnetron may then be driven into oscillation by superimposing short high voltage pulses (timed by a pulse programmer at normal logic voltages) onto this pedestal. If these take the voltage across the magnetron to the normal operating voltage, then the typical peak power output is obtained. In the studies at the University of Essex former Chemistry Department, we used an MG 5428[5] device from EEV (now e2v), with a potential peak power of 4kW limited to 4W mean. Initially, we modified a marine radar transmitter from Mars Electronics and this unit produced about 800W peak after modification. In order to get phase coherence the magnetron was fed with a continuous priming signal from a frequency multiplied crystal oscillator (via a circulator). The output is then a sequence of pulses with widths down to about 20 nanoseconds. The magnetron switches very quickly and shortens the rise times of the priming pulses it should be noted. The priming signal is applied 45 MHz from the normal magnetron frequency as noted by Nyswander[6] who first reported the pedestal technique. This means that an intermediate frequency is detected when the cw signal is fed into the mixer used to detect the echo signals. In principle, no low noise microwave amplifier need be used to amplify the detected signal as the 1/f noise of diode detectors is very small at 45Mhz.

The layout of the components we used is shown in figure 1a and in 1b the production of short pulses by the pedestal method. In Figure 2a the applied pulses and the echo are displayed on separate traces of the oscilloscope. In 2b a weak echo is shown.

In financial terms, the technique described here has many advantages. At the time this work was carried out a magnetron cost £100 whereas the TWTA was in the region of £30,000. The low noise amplifiers needed in a conventional set-up cost around £10,000. The only problem with the magnetron method would be production of the pedestal pulse generator: a good in-laboratory electronics facility is needed or one would have to go to a commercial custom electronics workshop, which has high voltage experience. Now that high voltage MOSFETs are available, this is not a very difficult design problem : an attempt to use TV flyback BJTs proved unsatisfactory as these suffered secondary breakdown[7] quite often! This method would be essential in the case of a general analytical instrument such as one used in process control, since the only commercial instruments using TWTA's cost well over £100, 000.

In Figure 3a. the phase coherence of the echoes is shown when priming is applied, in comparison to no priming, and in 3b the effect of changing the priming phase by 180 degrees.

The instrument described herein was used to characterise samples from the British Coal Bank, ranging from very high carbon content to around 60% carbon using phase memory times. [8]

Acknowledgements:

This note is based on work at the University of Essex, with the assistance of B.W.Ready (for computer interfacing) and N.L. Barnard (general electronic construction) in the Chemistry Department and it was financed by The Nuffield Foundation, The Engineering Board, Process Control Committee of the S.E.R.C., and British Coal (a sub-contract part of a European Coal and Steel Organisation project for characterisation of coals from the British Coal Bank). Many helpful discussions were held with departments of EEV, Ltd (this company became e2v, Ltd when the GEC/Marconi conglomerate was broken up) and various reearch workers in the 1980s including W. B. Mims, J. Freed, J. R. Norris, L. Kevan and S. Weissman.

References.

1.Personal communication at Bell Telephone Laboratories 1982 during the author's visit (part of a study tour financed by the Nuffield Foundation). See also reference 3.

2. Personal communication from R. Snelling, Consultant to EEV, Ltd

3. Personal Communication from C.R. Bender, (Fordham University, New York)

4. British Patent GB 2 235 775 B (1991)

5. The current equivalent manufactured by the successor company e2v is the MG4004

6. R.E. Nyswander and G.J. Auger, 1976
1st. International Pulsed Power Conference p.IIID-4/1 see also Us Patent 6,914,556 B1 of Jul. 5, 2005 , which seems to duplicate our patent ref. 4

7. pointed out by H.D.Kitchin, of Bournlea Instruments who rebuilt
our unit based on these devices and also produced a MOSFET unit for evaluation

8. ECSC Project No. 7220 – RC 857, 1991. Progress Report No.1

Figure 1a

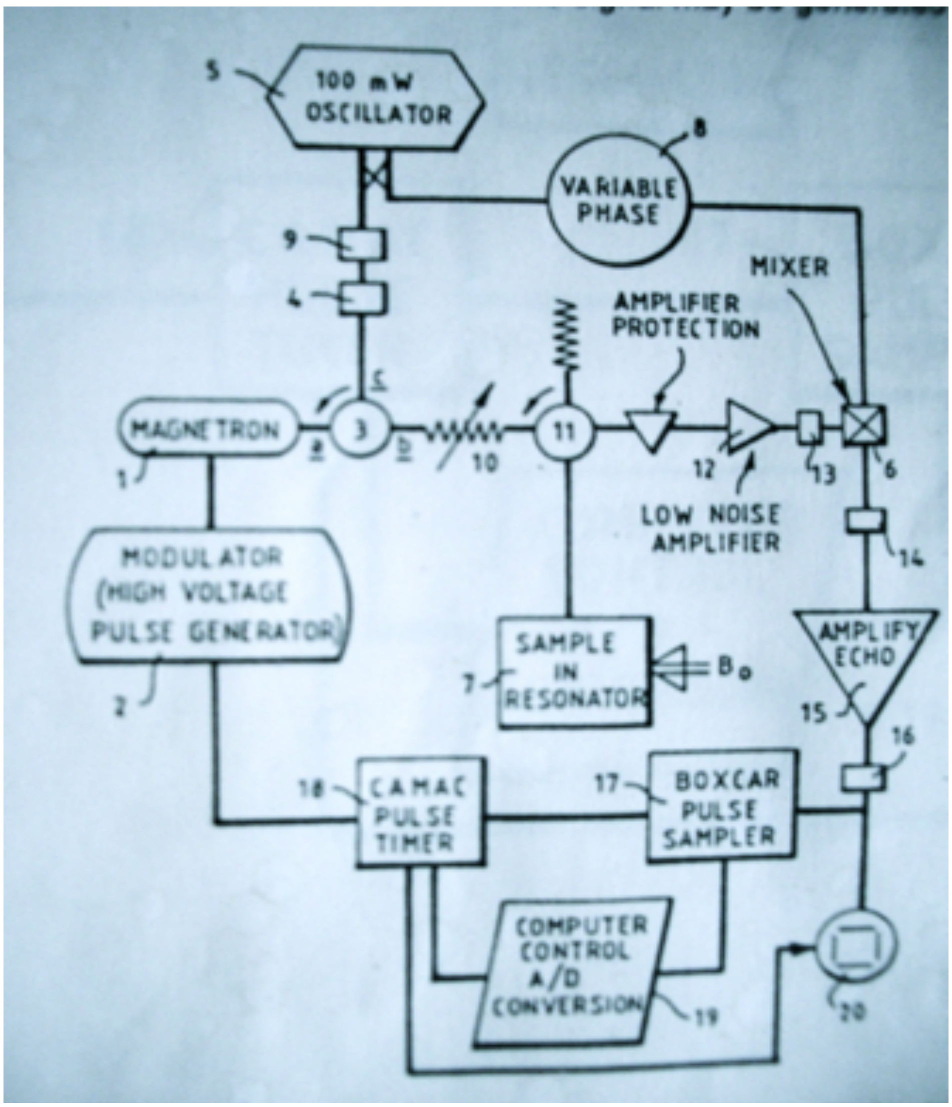


Figure 1b

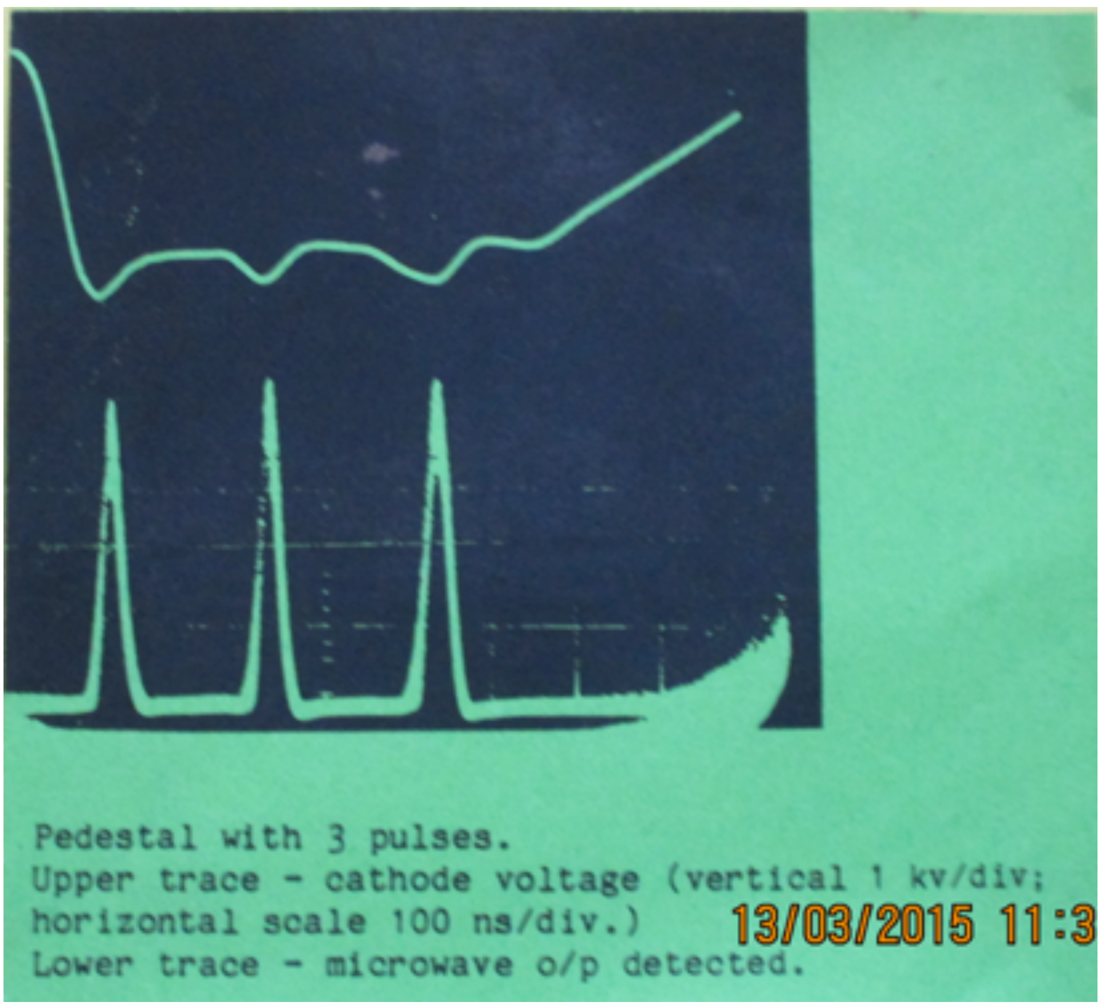

Pedestal with 3 pulses.
Upper trace - cathode voltage (vertical 1 kv/div;
horizontal scale 100 ns/div.)
13/03/2015 11:3
Lower trace - microwave o/p detected.

Figure 2a Strong echo from coal sample, microwave pulses 20 and 40 ns

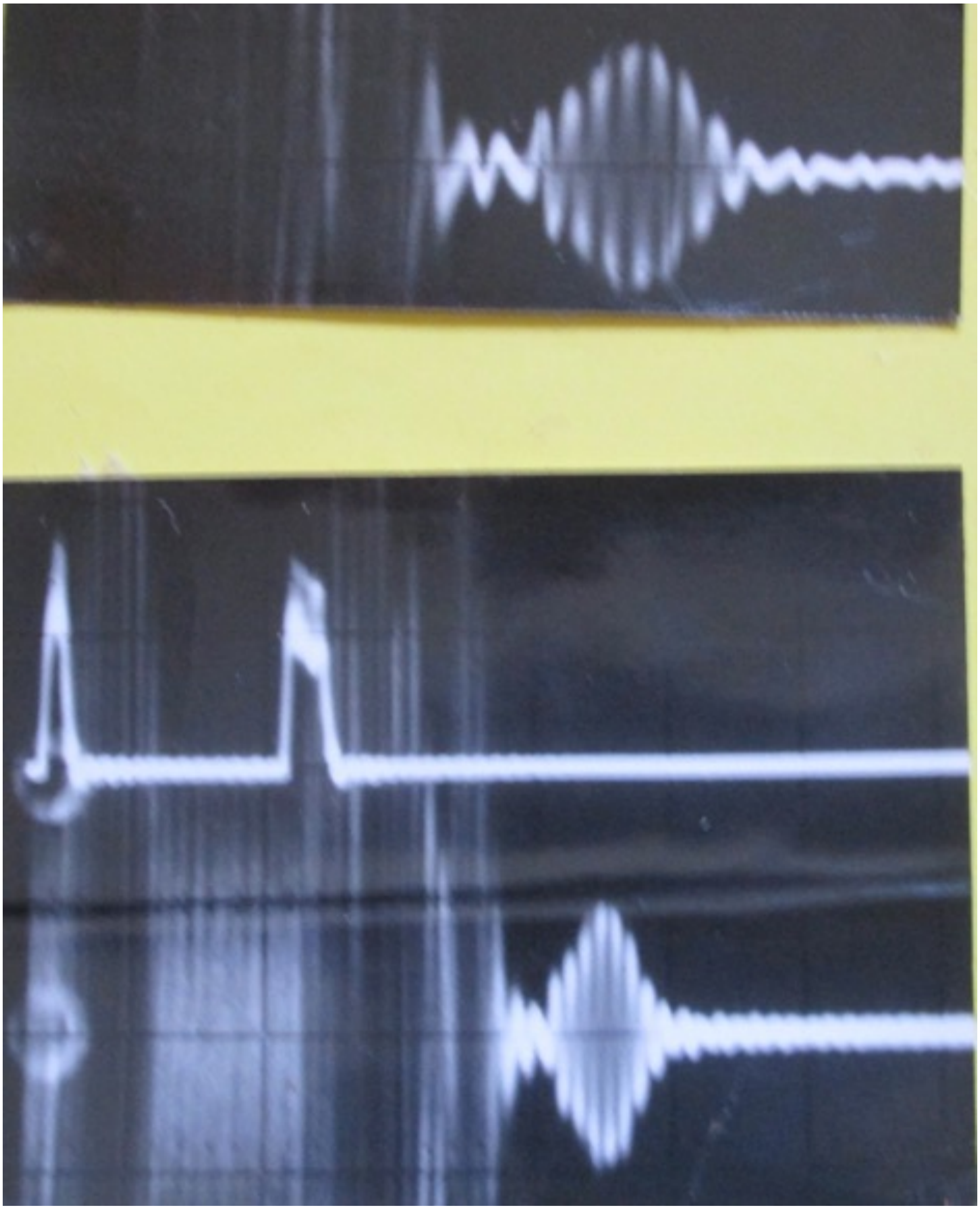


Figure 2b weak echo from Biphenyl radical in Boric acid glass , sample supplied by Professor J. Schmidt of Leiden Univeristy Huygens Laboratory.

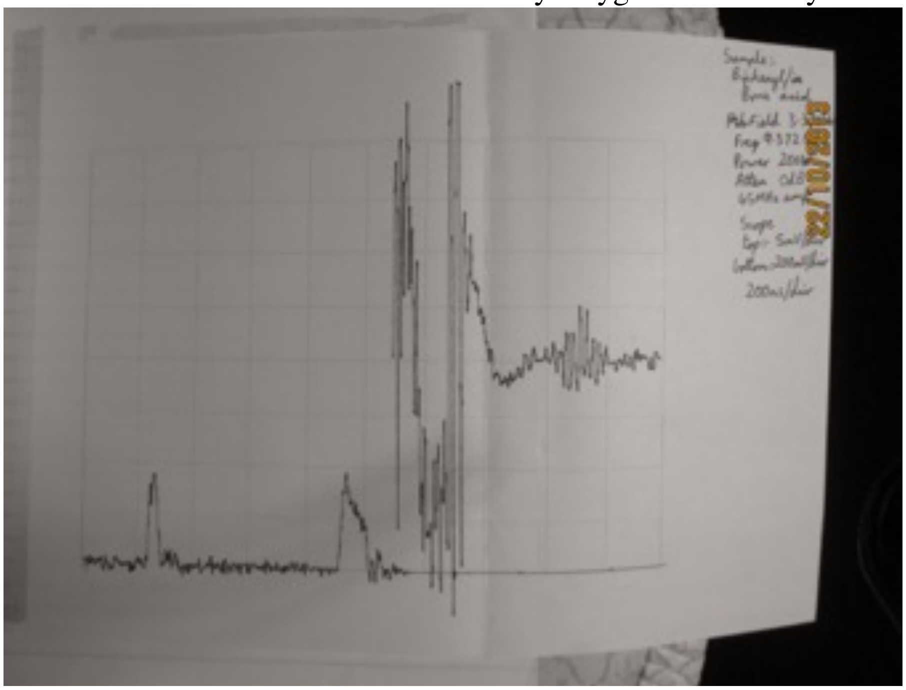


Figure 2c

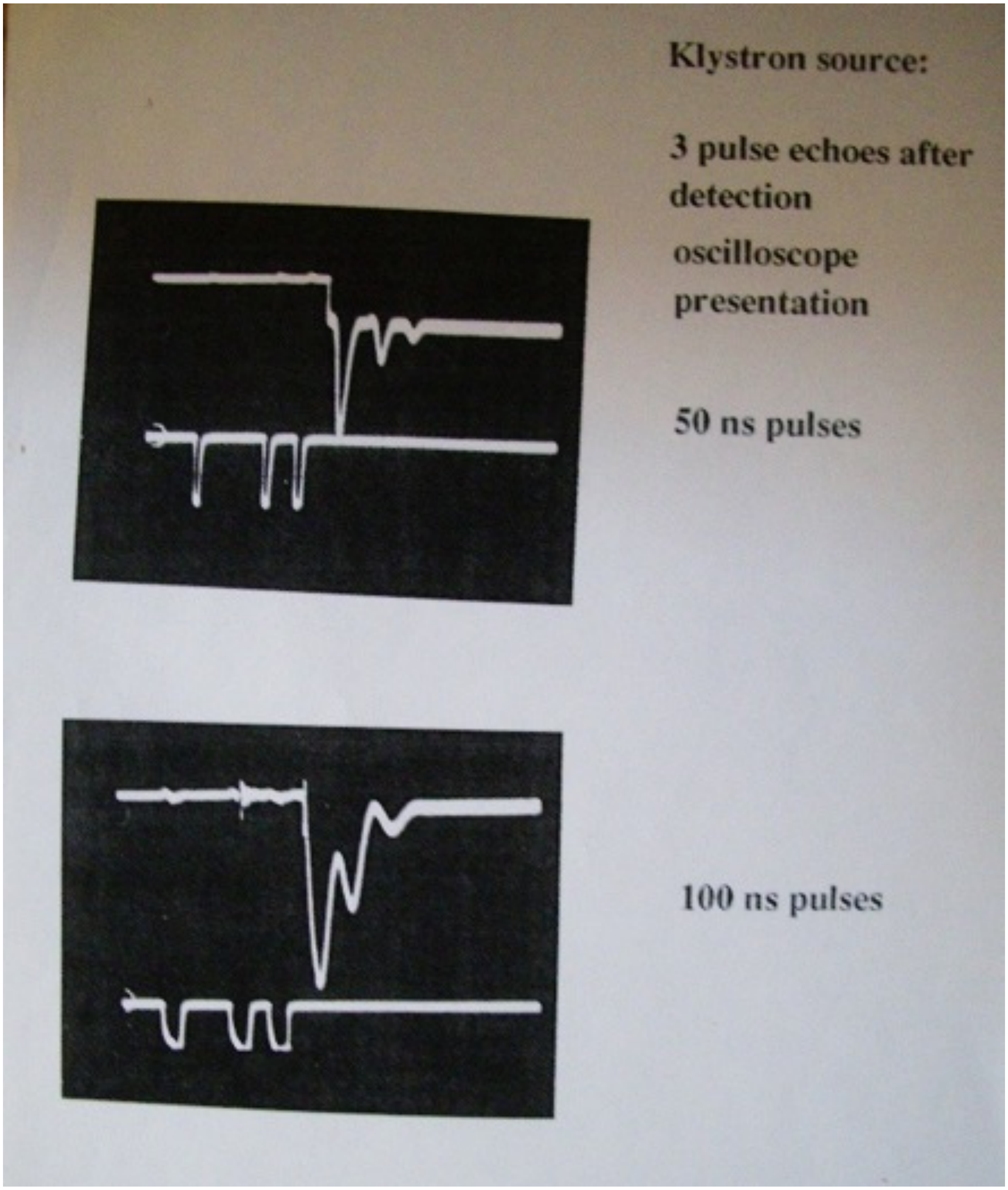

Klystron source:
3 pulse echoes after detection
oscilloscope presentation
50 ns pulses
100 ns pulses

Figure 3a Echoes with and without phase priming

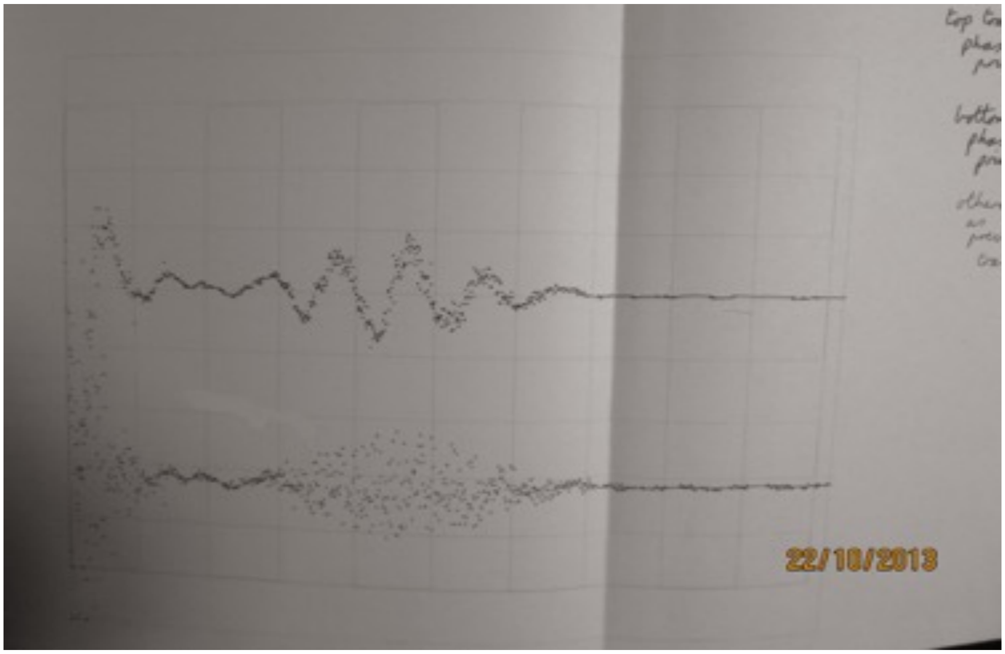
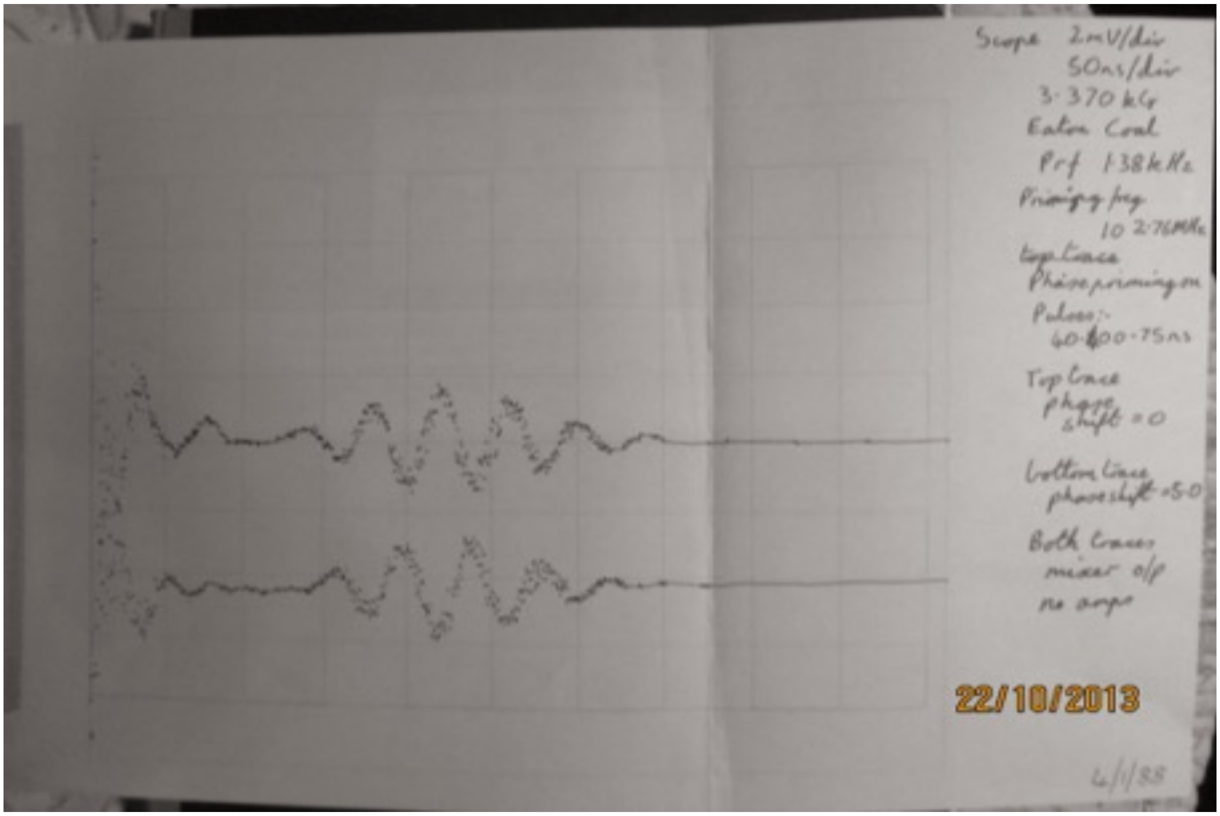


Figure 3b Echoes with 180 degree priming phase change


Scope 2mV/div
50ns/div
3·370 kG
Eaton Coal
Prf 1·38kHz
Priming freq
10 2·76MHz
top trace
Phase priming on
Pulses:-
40-100-75ns
Top trace
phase shift = 0
bottom trace
phaseshift = 5·0
Both traces
mixer o/p
no amps
22/10/2013
6/1/88